7.2 Types of Reactions

Reading Focus

Key Concepts

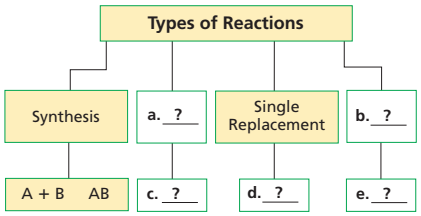
- What are the general types of chemical reactions?
- How did the discovery of subatomic particles affect the classification of reactions?

Vocabulary

- synthesis reaction
- decomposition reaction
- single-replacement reaction
- double-replacement reaction
- combustion reaction
- oxidation-reduction reaction

Reading Strategy

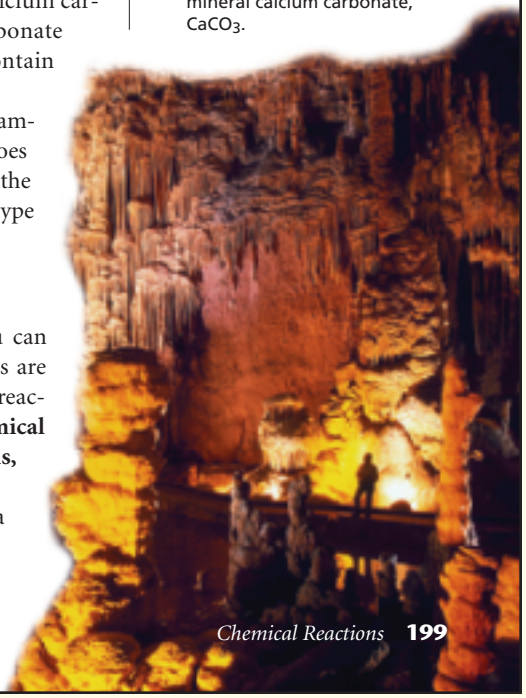
Previewing Skim the section and begin a concept map like the one below that identifies types of reactions with a general form. As you read, add the general form of each type of reaction.



The walls of the cave shown in Figure 9 are solid limestone. When hydrochloric acid is dropped on limestone, a chemical reaction occurs in which a gas is produced. Geologists can use this reaction to determine whether a rock sample contains the mineral calcium carbonate, $CaCO_3$. When a rock containing calcium carbonate reacts with hydrochloric acid, it fizzes. The bubbles contain carbon dioxide gas.

Many other reactions produce carbon dioxide. For example, heating limestone produces carbon dioxide. So does burning gasoline. However, just because two reactions have the same product, you cannot assume that they are the same type of reaction.

Figure 9 The walls and other formations of Blanchard Springs Caverns in Arkansas contain the mineral calcium carbonate, $CaCO_3$.



Classifying Reactions

Just as you can classify matter into different types, you can classify chemical reactions into different types. Reactions are often classified by the type of reactant or the number of reactants and products. **Some general types of chemical reactions are synthesis reactions, decomposition reactions, single-replacement reactions, double-replacement reactions, and combustion reactions.** Each type describes a different way in which reactants interact to form products.

Section Resources

Print

- ***Laboratory Manual,*** Investigations 7A and 7B
- ***Reading and Study Workbook With Math Support,*** Section 7.2
- ***Transparencies,*** Section 7.2

Technology

- ***Interactive Textbook,*** Section 7.2
- ***Presentation Pro CD-ROM,*** Section 7.2
- ***Go Online,*** NSTA SciLinks, Chemical reactions, Oxidation and reduction

Section 7.2

1 FOCUS

Objectives

7.2.1 **Classify** chemical reactions as synthesis, decomposition, single-replacement, double-replacement, or combustion reactions.

7.2.2 **Describe** oxidation-reduction reactions, and **relate** them to other classifications of chemical reactions.

Reading Focus

Build Vocabulary L2

Word Forms Ask students to write simple definitions of the words *synthesize, decompose,* and *replace.* Then, have students explain how these simple definitions relate to the terms *synthesis reaction, decomposition reaction, single-replacement reaction,* and *double-replacement reaction. (To synthesize is to combine and form a complex product, to decompose is to separate into basic parts, and to replace is to take or fill the place of.)*

Reading Strategy L2

a. Decomposition **b.** Double replacement **c.** $AB \longrightarrow A + B$
d. $A + BC \longrightarrow B + AC$
e. $AB + CD \longrightarrow AD + CB$

2 INSTRUCT

Classifying Reactions

Integrate Earth Science L2

Calcium carbonate in limestone rock is dissolved by water made acidic by carbon dioxide according to the following equation.

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2HCO_3^-$$

The reverse reaction deposits the calcium carbonate onto a limestone surface. (Note that reaction equilibrium is discussed in depth in Section 7.5.) In this way, water dripping in a limestone cave forms beautiful formations. Have students research cave formations. Ask, **What is the difference between stalactites and stalagmites?** *(Stalactites form on cave ceilings, while stalagmites form on cave floors.)*

Visual

Integrate Biology

L2

Biologists often call the decay of organic matter *decomposition* even when the reactions that take place do not follow the general form AB ⟶ A + B. While both meanings of *decomposition* are derived from the idea of separating objects into simpler parts, chemists use this term to describe a reaction that leads to the breakdown of a single compound. **Logical**

Teacher Demo

Exothermic Reaction

L2

Purpose Students observe a synthesis reaction.

Materials balance, evaporating dish, copper powder, ring stand, wire gauze, Bunsen burner, tongs

Procedure Measure and record on the board the mass of the evaporating dish. Measure out 10 g of copper powder and spread it evenly in the evaporating dish. Arrange the wire mesh on the ring stand so that it sits above the Bunsen burner. Place the evaporating dish on the wire mesh and light the Bunsen burner. Heat the copper powder in the evaporating dish for 10–15 minutes. Allow the evaporating dish and its contents to cool and then determine their total mass. Ask, **Was mass conserved in this reaction?** *(Students may answer no, based on the increase in mass.)* Have students calculate the mass of the synthesized product.

Expected Outcome The copper powder turns into black copper(II) oxide, and the product's mass is greater than the original mass of the copper powder. The additional mass comes from the oxygen, which is the other reactant in the synthesis reaction. **Visual, Logical**

Go Online NSTA SCILINKS

Download a worksheet on chemical reactions for students to complete, and find additional teacher support from NSTA SciLinks.

Figure 10 Sodium metal reacts vigorously with chlorine to form sodium chloride, NaCl.
Interpreting Photos *What evidence in this photograph tells you that a chemical reaction is taking place?*

Go Online NSTA SCILINKS

For: Links on chemical reactions
Visit: www.SciLinks.org
Web Code: ccn-1076

Synthesis

A **synthesis reaction** is a reaction in which two or more substances react to form a single substance. The reactants may be either elements or compounds. The product synthesized is always a compound. The general equation for a synthesis reaction is

$$A + B \longrightarrow AB$$

Figure 10 shows what happens when sodium reacts with chlorine. The product of this reaction is the compound sodium chloride, which appears as a whitish cloud of solid particles. You are probably more familiar with sodium chloride as table salt. You can describe the synthesis of sodium chloride with the following equation.

$$2Na + Cl_2 \longrightarrow 2NaCl$$

Another example of a synthesis reaction is hydrogen and oxygen reacting to form water.

$$2H_2 + O_2 \longrightarrow 2H_2O$$

This reaction is used to generate electricity for satellites and spacecraft.

Reading Checkpoint *What is a synthesis reaction?*

Decomposition

The opposite of synthesis is decomposition. A **decomposition reaction** is a reaction in which a compound breaks down into two or more simpler substances. The reactant in a decomposition reaction must be a compound. The products may be elements or compounds. The general equation for a decomposition reaction is

$$AB \longrightarrow A + B$$

When electricity passes through water, the water decomposes into hydrogen gas and oxygen gas. You can describe the decomposition of water by writing the following equation.

$$2H_2O \longrightarrow 2H_2 + O_2$$

Notice that this reaction is the opposite of the synthesis of water.

Another example of decomposition occurs in the making of cement. Cement factories use a giant kiln, or oven, to heat a mixture of clay and limestone. The heat causes the calcium carbonate in the limestone to decompose into lime, CaO, and carbon dioxide.

$$CaCO_3 \longrightarrow CaO + CO_2$$

The carbon dioxide escapes the kiln through a smokestack. The clay-and-lime mixture is cooled and ground into cement powder.

The How It Works box on page 201 describes a decomposition reaction that is used to make automobiles safer.

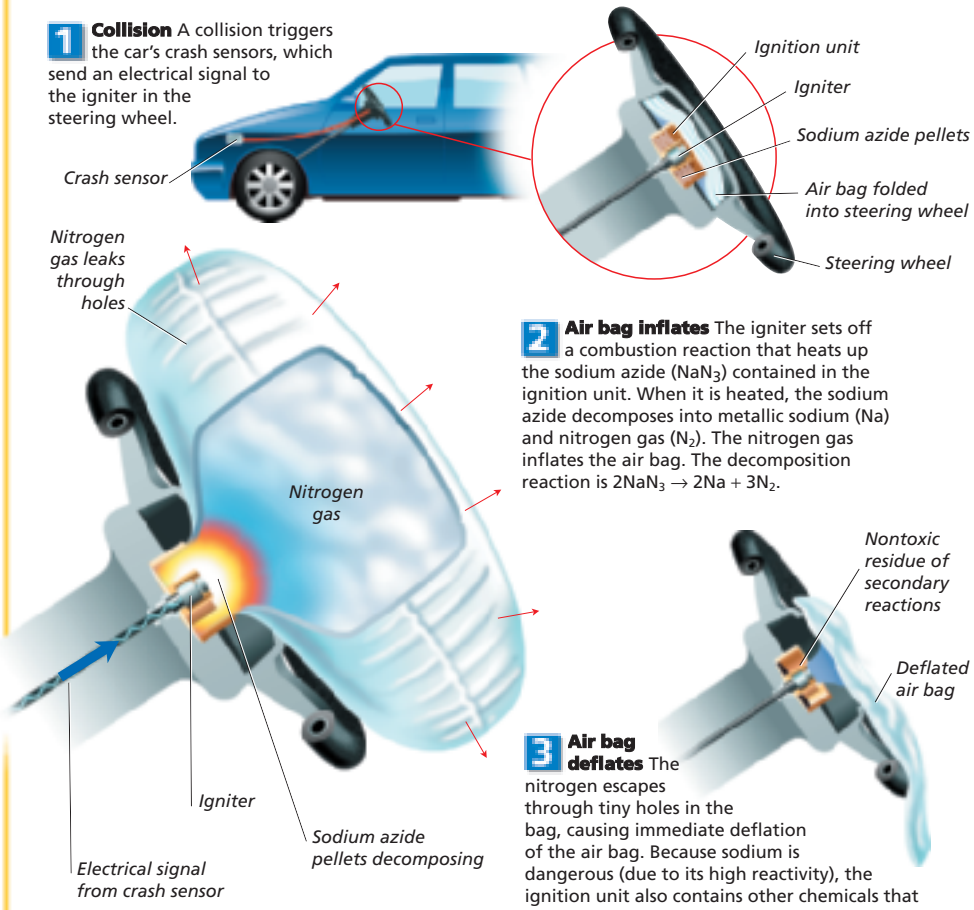
Customize for English Language Learners

Discussion
Write the general equations for synthesis, decomposition, single-replacement, and double-replacement reactions on the board. Use word equations to explain what is happening in each reaction. For example, you might say, **In a synthesis reaction, chemical A reacts (combines) with chemical B to form a new chemical compound made up of the same elements as those in chemicals A and B.** Have students comment on how the equations are alike and how they are different. They may point out that the equation for synthesis appears to be the reverse of the equation for decomposition. Also, they may notice that the replacement reactions involve different particles changing places. Encourage students to use familiar words when describing their observations.

Automobile Safety: Air Bags

Air bags are inflatable cushions built into a car's steering wheel or dashboard. In a crash, the bags inflate, protecting both the driver and the passenger. The whole process takes 0.04 second. **Interpreting Diagrams** *What is the source of the gas that fills an air bag?*

Testing air bags
Air bags have been shown to reduce the risk of serious injury in a head-on collision by 30 percent. New cars have air bags on both the driver and passenger sides.



DK HOW It Works

Automobile Safety: Air Bags L2

The force of the reaction that inflates an air bag causes the air bag to break out of the steering wheel at up to 200 miles per hour. One way that manufacturers help the bag withstand the friction of this fast movement is by lubricating the bag with powders, such as talcum powder or cornstarch.

Interpreting Diagrams The source of the nitrogen gas that fills an air bag is the reacting sodium azide contained in the ignition unit. When the sodium azide pellets are heated, they decompose into sodium metal and nitrogen gas.

Visual

For Enrichment L3

Have students research the benefits and drawbacks of including air bags in automobiles. They may want to find out about the types of injuries caused and prevented by air bags as well as the types of injuries that air bags cannot prevent. **Verbal**

Address Misconceptions L2

Many students incorrectly think that the reactants are still present after a reaction has gone to completion. Challenge this misconception by discussing the reaction that takes place when an air bag inflates. After the class has read the feature on air bags, ask students where the nitrogen gas comes from when an air bag inflates. Explain that the nitrogen gas produced from the decomposition of solid sodium azide is exactly like the nitrogen gas in air. Apply this concept later when the class reads about single-replacement reactions that have solid reactants and products.
Verbal

Answer to . . .

Figure 10 *The formation of a cloudy substance and the release of energy (seen in the photo as light) are evidence that a chemical reaction is taking place.*

Reading Checkpoint *A synthesis reaction is a reaction in which two or more substances react to form a single substance.*

Use Visuals

L1

Figure 11 Students may note that in the reaction between copper and silver nitrate, the water (part of the silver nitrate solution) doesn't appear as a reactant in the accompanying chemical equation in the text. Ask, **What evidence is there of a chemical change in Figure 11?** *(The solution changes color, and silver crystals form on the wire.)* Explain that when a compound dissociates in water, a physical change has taken place. The water and the dissolved substance remain chemically unchanged. The flask contains the same number of water molecules before and after the reaction takes place. Ask, **If you were to include water in the chemical equation, where would you place it?** *(Water would be on both sides of the equation with equivalent coefficients.)* Explain that just as in a math equation, you can cancel equivalent expressions that appear on both sides of the equation. **Visual**

Figure 11 A single-replacement reaction occurs when copper wire is submerged in a solution of silver nitrate. As the copper replaces the silver in the silver nitrate solution, the solution turns blue, and silver crystals form on the wire.

Figure 12 Potassium reacts with water in a single-replacement reaction that produces hydrogen gas and potassium hydroxide.

Single Replacement

A **single-replacement reaction** is a reaction in which one element takes the place of another element in a compound. Single-replacement reactions have the general form

$$A + BC \longrightarrow B + AC$$

Suppose you dip a coil of copper wire into a solution of silver nitrate and water, as shown in Figure 11. A vivid chemical reaction takes place as the solution turns blue and the submerged part of the wire becomes coated with a silvery metal. In this reaction, the copper replaces the silver in silver nitrate to form copper(II) nitrate. The equation for this reaction is

$$Cu + 2AgNO_3 \longrightarrow 2Ag + Cu(NO_3)_2$$

Notice that one of the products is silver, which you can see adhering to the wire in Figure 12. The other product, copper(II) nitrate, gives the solution its blue color.

Recall that alkali metals are very reactive elements. Figure 12 shows potassium reacting with water. This is another example of a single-replacement reaction, as the element potassium replaces hydrogen in water to form potassium hydroxide, KOH.

$$2K + 2H_2O \longrightarrow H_2 + 2KOH$$

The heat produced by this chemical reaction causes the hydrogen gas to ignite explosively.

Reading Checkpoint *What is a single-replacement reaction?*

Facts and Figures

Activity Series Through experimentation, chemists can compile an activity series, a list of elements arranged in decreasing activity. The elements at the top of the list are the most reactive and will replace those elements at the bottom of the list when they are in compounds. For example, according to the activity series to the right, copper will replace silver in a single-replacement reaction, as in the reaction described in the text. Using the activity series, you could correctly predict that the following single-replacement reaction would take place.

$$Fe + CuSO_4 \longrightarrow FeSO_4 + Cu$$

Activity Series of Metals

Decreasing Reactivity ↓

- Potassium (K)
- Calcium (Ca)
- Magnesium (Mg)
- Zinc (Zn)
- Iron (Fe)
- Lead (Pb)
- Hydrogen (H)
- Copper (Cu)
- Silver (Ag)

Double Replacement A **double-replacement reaction** is one in which two different compounds exchange positive ions and form two new compounds. The general form of a double replacement reaction is

$$AB + CD \longrightarrow AD + CB$$

Notice that two replacements take place in this reaction. Not only is A replacing C, but C is also replacing A.

Solutions of lead(II) nitrate, $Pb(NO_3)_2$, and potassium iodide, KI, are both colorless. However, when these solutions are mixed, as shown in Figure 13, a yellow precipitate forms as a result of a double-replacement reaction. The equation for this reaction is

$$Pb(NO_3)_2 + 2KI \longrightarrow PbI_2 + 2KNO_3$$

The lead ions in $Pb(NO_3)_2$, trade places with the potassium ions in KI. The products are lead(II) iodide, PbI_2, which precipitates out of solution, and potassium nitrate, KNO_3, which remains in solution.

When geologists test the calcium carbonate content in a rock, they make use of the following double-replacement reaction.

$$CaCO_3 + 2HCl \longrightarrow CaCl_2 + H_2CO_3$$

One of the products of this reaction is calcium chloride, $CaCl_2$. The other product is carbonic acid, H_2CO_3, which decomposes into carbon dioxide gas and water.

$$H_2CO_3 \longrightarrow CO_2 + H_2O$$

Figure 13 When potassium iodide solution is poured into a solution of lead(II) nitrate, a double-replacement reaction takes place. Lead(II) iodide forms as a yellow precipitate.
Comparing and Contrasting *How does a double-replacement reaction differ from a single-replacement reaction?*

Quick Lab

Identifying a Type of Reaction

Materials

piece of zinc, copper(II) sulfate ($CuSO_4$) solution, 250-mL beaker, tongs, paper towel

Procedure

1. Place the zinc in the beaker and add enough $CuSO_4$ solution to cover the zinc as shown. **CAUTION** *Be careful when using chemicals. Copper sulfate is toxic.*
2. After 5 minutes, carefully remove the zinc from the solution using the tongs and place the zinc on the paper towel to dry. Observe any changes that have occurred to the zinc and the solution of $CuSO_4$. **CAUTION** *Follow your teacher's instructions for disposal of used chemicals. Wash your hands with soap or detergent before leaving the laboratory.*

Analyze and Conclude

1. **Observing** What clues indicate that a chemical reaction has taken place?
2. **Applying Concepts** What were the reactants in this reaction? What were the products? Write a balanced chemical equation for the reaction.
3. **Classifying** Is this a single-replacement or double-replacement reaction? Explain.

Quick Lab

Identifying a Type of Reaction

L2

Objective
After completing this activity, students will be able to
- determine whether a chemical reaction has occurred.
- identify a single-replacement reaction.

Skills Focus **Observing, Predicting**

Prep Time 10 minutes

Advance Prep Purchase zinc strips or cut a zinc sheet into 1" × 2" pieces. While wearing safety goggles and heavy gloves, file down all rough edges. To prepare 0.1 M $CuSO_4$: Dissolve 2.5 g $CuSO_4 \cdot 5H_2O$ in enough water to make 100 mL of solution. Be sure to take proper safety precautions.

Class Time 15 minutes

Safety Students should wear safety goggles, lab aprons, and disposable plastic gloves. They should tie back long hair and secure any loose clothing.

Expected Outcome The section of the zinc strip exposed to the $CuSO_4$ solution will have a distinct copper metal coating and the copper(II) sulfate solution will become darker and less blue in color.

Analyze and Conclude
1. The $CuSO_4$ solution turned less blue and the zinc became coated with reddish copper.
2. Zn and $CuSO_4$; Cu and $ZnSO_4$; $Zn + CuSO_4 \longrightarrow Cu + ZnSO_4$
3. This is a single-replacement reaction because one element replaces another element in a compound. **Visual**

For Enrichment

L2

Have students examine other single metal replacement reactions by placing copper and magnesium in $AgNO_3$, $CuSO_4$, $MgSO_4$, and $ZnSO_4$ solutions. The copper strip will react with $AgNO_3$, and the magnesium strip will react with $AgNO_3$, $CuSO_4$, and $ZnSO_4$. **Kinesthetic**

Answer to . . .

Figure 13 *In a double-replacement reaction, two different compounds exchange positive ions and form two new compounds.*

Reading Checkpoint *A reaction in which one element takes the place of another element in a compound*

Build Reading Literacy

L1

Preview Refer to page **36D** in **Chapter 2**, which provides the guidelines for previewing.

Have students preview the text on pp. 204 and 205 related to oxidation and reduction reactions. They should note the headings, the bold-faced key ideas, and the chemical equations. Help students activate their prior knowledge by reviewing the role electrons play in ionic and covalent bonding.
Verbal

Reactions as Electron Transfers

Build Science Skills

L2

Classifying Many kinds of reactions are also classified as redox reactions. For example, all combustion reactions are also redox reactions. The easiest reactions to identify as redox reactions contain pure elements. Have students search the section and identify these redox reactions, which have a product or a reactant that is an element.
($2Na + Cl_2 \longrightarrow 2NaCl$;
$2H_2 + O_2 \longrightarrow 2H_2O$;
$2H_2O \longrightarrow 2H_2 + O_2$;
$Cu + 2AgNO_3 \longrightarrow Cu(NO_3)_2 + 2Ag$;
$2K + 2H_2O \longrightarrow H_2 + 2KOH$;
$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$)
Logical

Figure 14 A Bunsen burner generates heat and light by the combustion of natural gas. **Interpreting Photos** *What reactants or products are visible in the reaction shown above?*

Combustion

A **combustion reaction** is one in which a substance reacts rapidly with oxygen, often producing heat and light. The burning of natural gas, shown in Figure 14, is an example of combustion. The main component of natural gas is methane, CH_4. When methane burns in an unlimited supply of oxygen, the following reaction occurs.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

The products of the reaction are carbon dioxide and water. The combustion of methane also generates both heat and light.

By now you know the chemical equation for the combustion of hydrogen.

$$2H_2 + O_2 \longrightarrow 2H_2O$$

Notice that you could also classify this reaction as the synthesis of water. The classifications for chemical reactions sometimes overlap.

Reactions as Electron Transfers

So far, you have learned that chemical reactions can be identified by the type of reactant or by the number of reactants and products. For example, in a combustion reaction one of the reactants must be oxygen. In a synthesis reaction, two or more reactants combine to form a single product.

As scientists learned more about the structure of the atom, they found different ways to describe how reactions take place. **The discovery of subatomic particles enabled scientists to classify certain chemical reactions as transfers of electrons between atoms.** A reaction in which electrons are transferred from one reactant to another is called an **oxidation-reduction reaction,** or redox reaction.

Figure 15 Calcium oxide, or lime, is produced when calcium burns in the presence of oxygen. In this reaction, the calcium is oxidized and the oxygen is reduced.

Oxidation

For a long time, people have known that metals react with oxygen. Calcium, for instance, reacts with oxygen and forms calcium oxide (CaO), shown in Figure 15. Iron reacts with oxygen and forms rust, or iron(III) oxide (Fe_2O_3). These types of synthesis reactions, in which a metal combines with oxygen, traditionally have been classified as oxidations.

When calcium reacts with oxygen, the following reaction takes place.

$$2Ca + O_2 \longrightarrow 2CaO$$

Notice that while the atoms of both reactants (Ca and O_2) are neutral, the product of the reaction is a compound composed of ions (Ca^{2+} and O^{2-}). When calcium reacts with oxygen, each neutral calcium atom loses two electrons and becomes a calcium ion with a charge of 2+.

$$Ca \longrightarrow Ca^{2+} + 2e^-$$

Facts and Figures

Corrosion of Metals Rust (Fe_2O_3) can result from oxygen and water coming into contact with iron. The corrosion of iron can result in the formation of many substances, including iron(II) oxide, FeO, and hydrated iron(III) oxide, $Fe_2O_3 \bullet nH_2O$. Iron is not the only metal that corrodes. Uncoated aluminum objects oxidize to form white Al_2O_3. Jewelry made of silver tarnishes over time, forming black Ag_2S. Copper pots often develop a distinctive green patina when exposed to the elements.

Any process in which an element loses electrons during a chemical reaction is called oxidation. A reactant is oxidized if it loses electrons. Note that the modern definition of oxidation is much broader than the original meaning. Oxygen doesn't always have to be present in order for an element to lose electrons. For example, when sodium reacts with chlorine, each neutral sodium atom loses one electron and becomes a sodium ion, Na^+.

Reduction As calcium atoms lose electrons during the synthesis of calcium oxide, the oxygen atoms gain electrons. As each neutral oxygen atom gains two electrons, it becomes an ion with a charge of 2−.

$$O + 2e^- \longrightarrow O^{2-}$$

The process in which an element gains electrons during a chemical reaction is called reduction. A reactant is said to be reduced if it gains electrons.

Oxidation and reduction always occur together. When one element loses electrons, another element must gain electrons. Note that oxidation-reduction reactions do not always involve complete transfers of electrons. For example, in the synthesis of water, hydrogen is oxidized as it partially loses electrons. Oxygen is reduced as it partially gains electrons.

Go Online NSTA SCILINKS

For: Links on oxidation and reduction
Visit: www.SciLinks.org
Web Code: ccn-1072

Section 7.2 Assessment

Reviewing Concepts

1. What are five general types of reactions?
2. How did the discovery of subatomic particles affect the classification of reactions?
3. The synthesis of water is described by the equation $2H_2 + O_2 \longrightarrow 2H_2O$. How is the decomposition of water related to this reaction? Explain, using a chemical equation.
4. Explain the difference between a single-replacement reaction and a double-replacement reaction.
5. Propane, C_3H_8, is frequently used in camping stoves. When propane undergoes combustion, what are the products formed?
6. Is the reaction represented by the following equation a redox reaction? Explain your answer.

$$2Hg + O_2 \longrightarrow 2HgO$$

Critical Thinking

7. **Predicting** What is the product of the synthesis reaction between magnesium and iodine? Explain your answer.
8. **Classifying** Identify these reactions as synthesis, decomposition, single replacement, double replacement, or combustion.
   a. $Pb(NO_3)_2 + 2HCl \longrightarrow PbCl_2 + 2HNO_3$
   b. $2C_2H_6 + 7O_2 \longrightarrow 4CO_2 + 6H_2O$
   c. $Ca + 2HCl \longrightarrow CaCl_2 + H_2$
   d. $2SO_2 + O_2 \longrightarrow 2SO_3$

Writing in Science

Explanatory Paragraph Write a paragraph explaining why the formation of water can be classified as a synthesis, combustion, or oxidation-reduction reaction.

3 ASSESS

Evaluate Understanding L2

Have students draw and label illustrations of different reactions on index cards. Have them exchange the cards and practice identifying each type of reaction.

Reteach L1

Make a chart of the number of reactants and products each reaction has.

Writing in Science

Synthesis: because two substances (oxygen and hydrogen) react to form a single substance (water); combustion: because the hydrogen reacts rapidly with oxygen, producing energy; and oxidation-reduction: because electrons are partially transferred from the hydrogen atoms to the oxygen

Interactive Textbook If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 7.2.

Go Online NSTA SCILINKS

Download a worksheet on oxidation and reduction for students to complete, and find additional teacher support from NSTA SciLinks.

Answer to . . .

Figure 14 *None can be seen. (The natural gas is being fed through the tubing; the oxygen reacting with the gas is colorless; and the carbon dioxide and water produced are both colorless.) However, the energy released by the reaction can be seen in the blue flame.*

Section 7.2 Assessment

1. Synthesis reaction, decomposition reaction, single-replacement reaction, double-replacement reaction, and combustion reaction
2. The discovery of subatomic particles allowed scientists to classify certain reactions as transfers of electrons between atoms.
3. In the reaction $2H_2 + O_2 \longrightarrow 2H_2O$, water is formed from its elements. During the decomposition of water, water is broken down into its elements, according to the equation $2H_2O \longrightarrow 2H_2 + O_2$.
4. In a single-replacement reaction, an element replaces another element in one compound. In a double-replacement reaction, two elements replace each other in two different compounds.
5. Carbon dioxide and water
6. Yes, this is a redox reaction because electron transfer takes place. The charge of mercury changes from 0 to 2+ (oxidation). The charge of oxygen changes from 0 to 2− (reduction).
7. MgI_2. In ionic compounds, magnesium has a charge of 2+ and iodine has a charge of 1−.
8. a. Double replacement
b. Combustion
c. Single replacement
d. Synthesis